

UCSB-ATR(1) Irradiation Experiment Overview

participants

G. Robert Odette, Takuya Yamamoto,
Doug Klingensmith, Ben Sams (UCSB)

Gregg Wachs, James I. Cole, Paul E. Murrey (INL)

Brian Wirth (UCB)

Stuart Maloy(LANL)

Jeremy Busby(ORNL)

Mychailo Toloczko, Rick Kurtz (PNNL)

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Outline

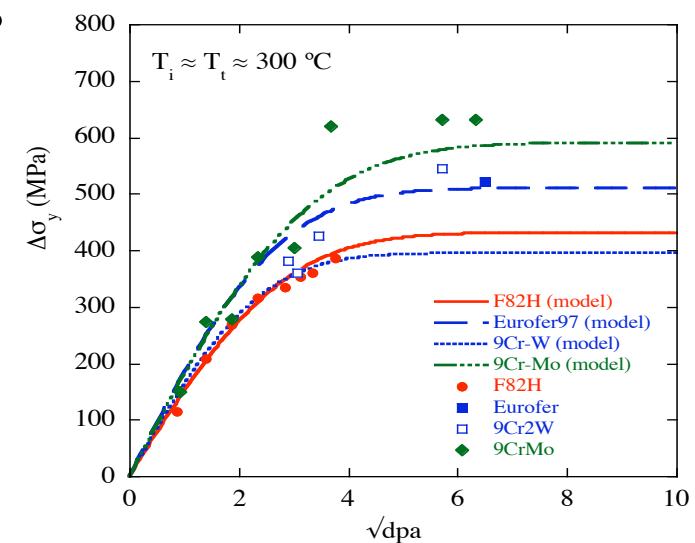
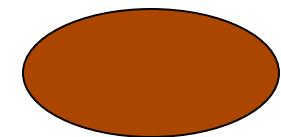
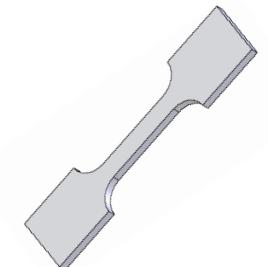
- Objectives of the irradiation experiment
- Design of the irradiation capsule
 - irradiation variable (fluence, flux, temperature) matrix
 - thermal design and analyses
- Plan for post-irradiation examination (PIE)

Objectives - 1

- **Create library of irradiated alloys**

1. Irradiation hardening/softening database- $288 \sim 750 \text{ }^{\circ}\text{C}$

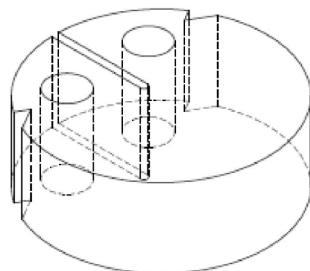
- Disc Multipurpose Coupon (DMC) Hv, Tensile for 6 TMS (tempered martensitic steels), 10 NFA (nano-structured ferritic alloys) and 1 SS (austenitic stainless steels)
- Refine semi-empirical hardening models
- Effects of metallurgical variables
- Micromechanical models of constitutive, flow instability and failure ductility properties
- Irradiation-thermal aging instability synergisms at higher T



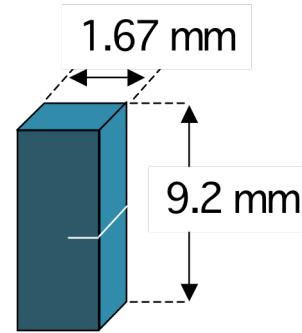
Objectives - 2

2. Fracture Mechanics Studies

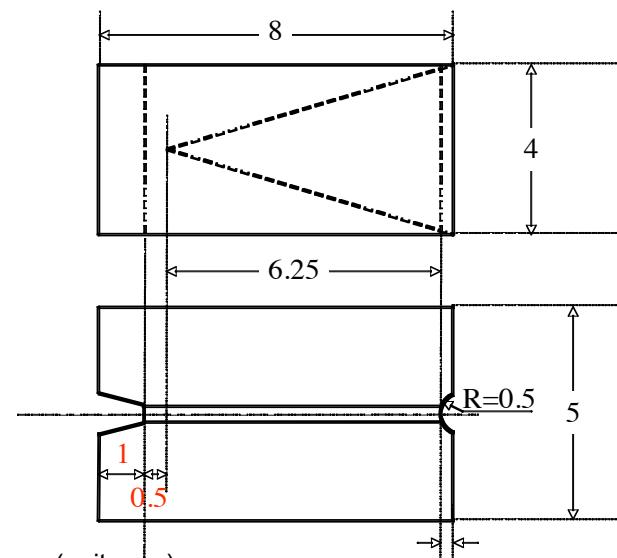
- Master curve (MC) - ΔT_o for 4 TMS using disc compact tension (DCT) specimens
- Mini bend bar tests on 2 TMS and 1 NFA
- DMC-Ball punch tests
- Chevron notch specimen with wedge loading (CHW) for 1 TMS (technique development)



DCT ($\phi 10 \times 3.7t$ mm)



DFMB



CHW

Objectives - 3

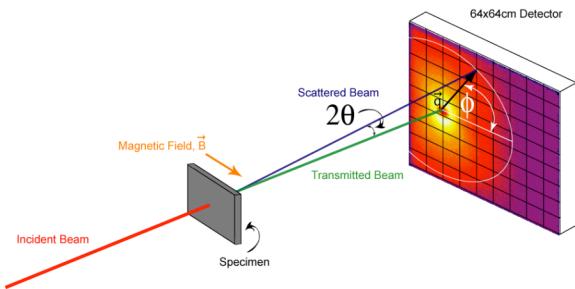
3. Microstructure Studies

– State of the art tools

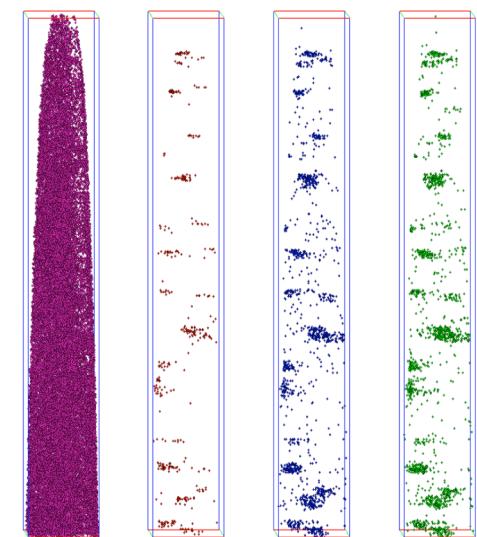
- SANS (small angle neutron scattering)
- TEM (transmission electron microscopy)
- APT (atom probe tomography)
- PAS (positron annihilation spectroscopy)
- Various X-ray based techniques and,
- Specimen preparation by FIB (focused ion-beam) machining

– “Lending library” for various techniques and researchers through collaborations

– Microstructurally-based physical models of the deformation and fracture of irradiated alloys



SANS



APT

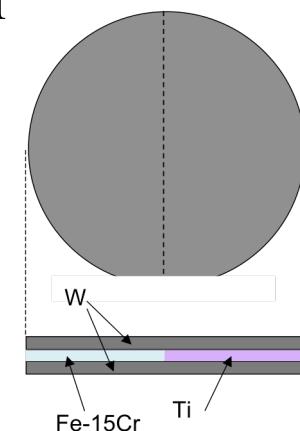
Objectives - 4

4. Model alloys and systems

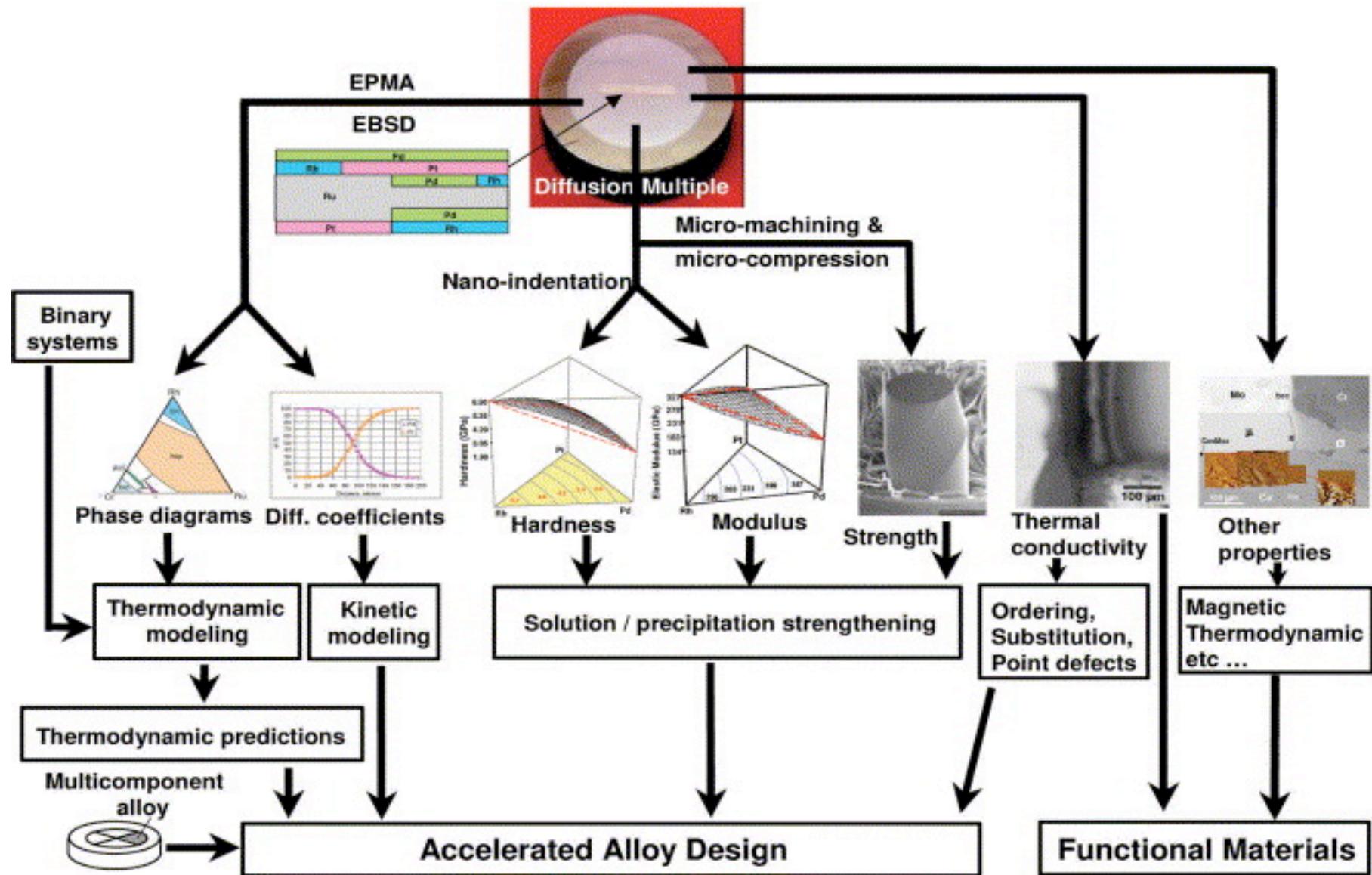
- Fe-0-18 % Cr for Cr effects on defects and α'
- Other model and developmental alloys
- RPV steels

5. Diffusion multiple (DM) experiments

- Bonded assemblies of up to 4 elements
- Equilibrium phase boundaries and inter-diffusion rates in binary ~ quaternary or higher systems
- Microstructural-microanalytical techniques
- First experiment under irradiation



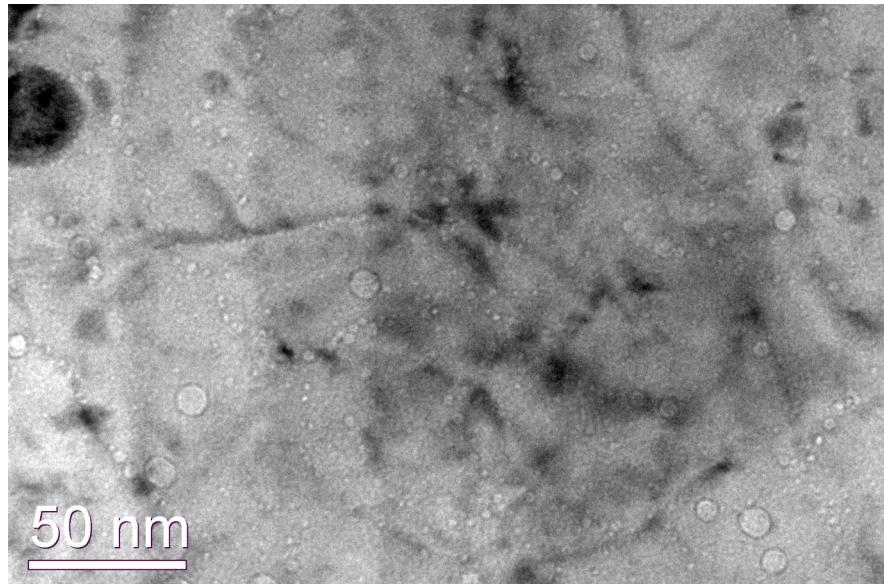
DM Approach



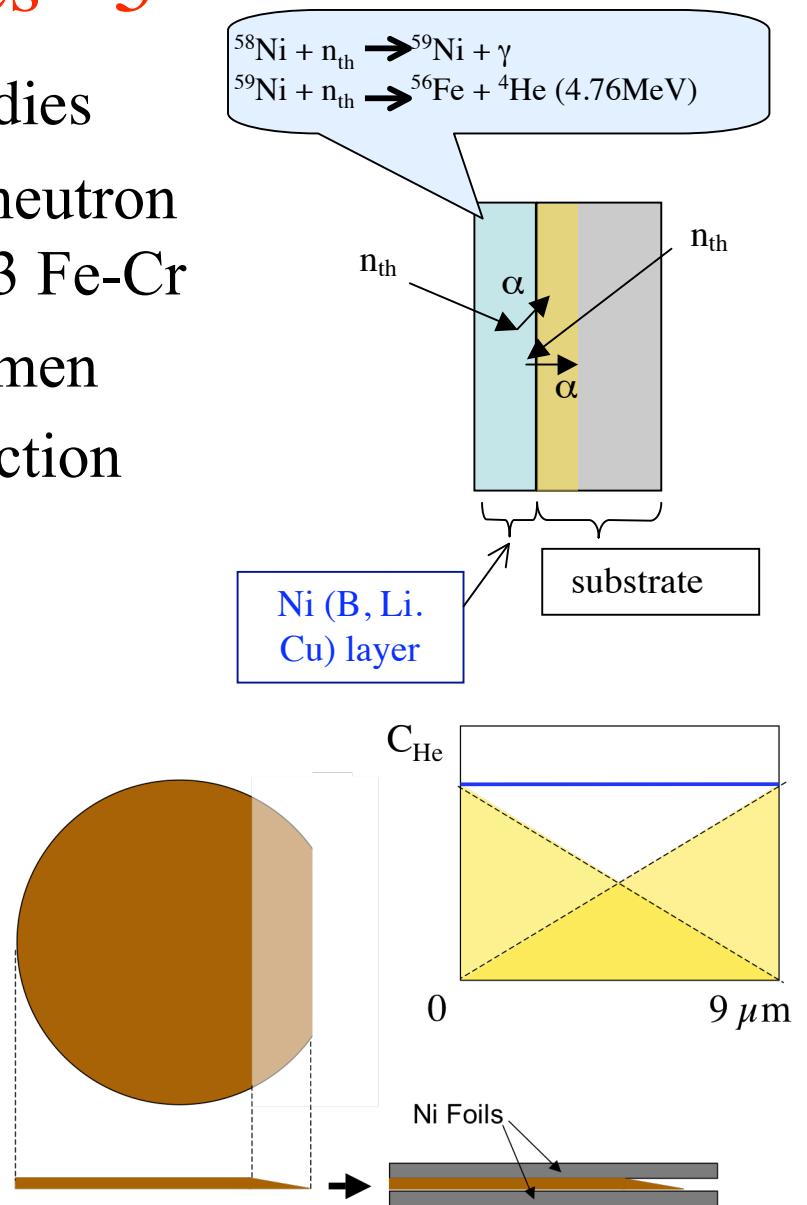
By Zhao, J.C.

Objectives - 5

- In-situ Ni-foil He implantation studies
 - Up to 150 appm He as well as neutron damage in 3 TMS, 6 NFA and 3 Fe-Cr
 - Wedge geometry for thin specimen ($\approx 9 \mu\text{m}$) thick foil two-sided injection



TMS F82H-mod.3 500°C, 9 dpa, 380 appm He



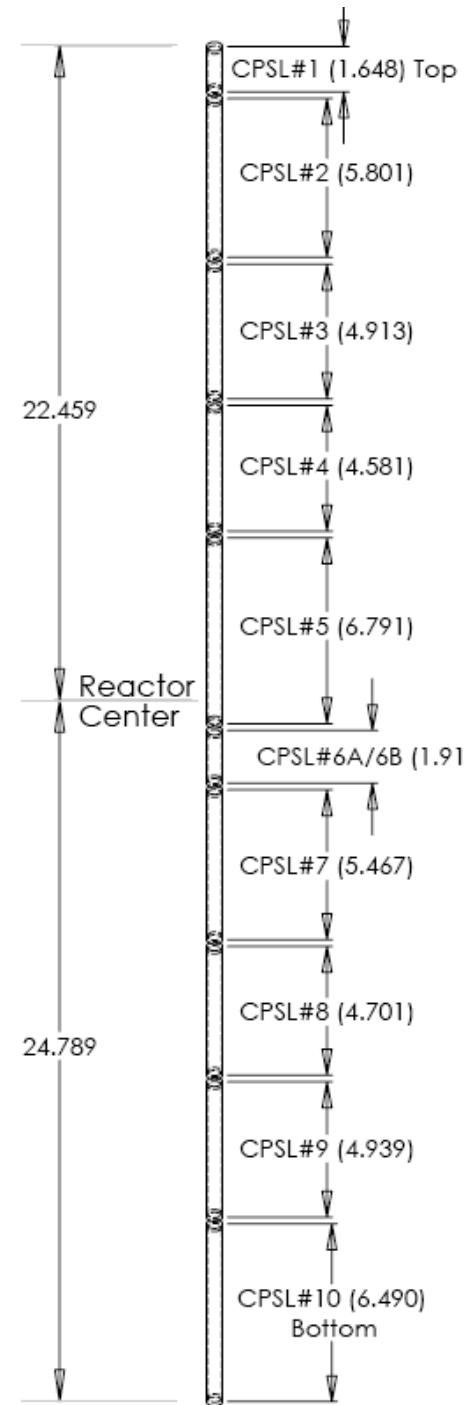
Material and Specimen Summary

Material		Specimen
TMS	F82H-IEA/Mod.3, Eurofer 97, T91, HT9, NF616	DMC, He-implanter Tensile, DTS,
NFA	MA956, 957, PM2000, 9Cr-YWT, 14CrYWT (5 heats), 15Cr-YWT	DCT, DFMB, Chevron Wedge, Notched Disc
SS	Cast SS	
RPVS Model alloy	A533B-type alloys (9), Fe-base alloys (OVs), Fe-xCr, MAR-aged alloy	DMC
DM Bond	Fe-Cr/W/Ti, Fe-Cr/Ni/W, Fe/Cu/Ni/W	

Capsule Summary

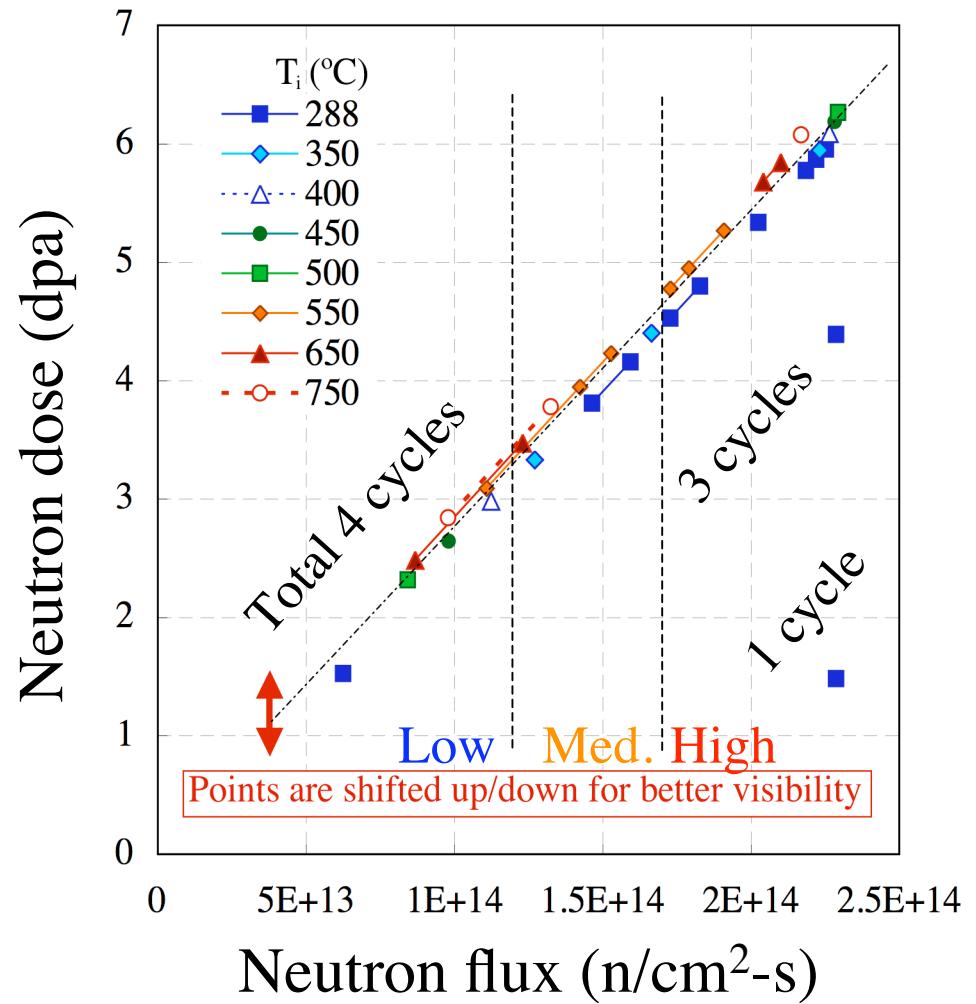
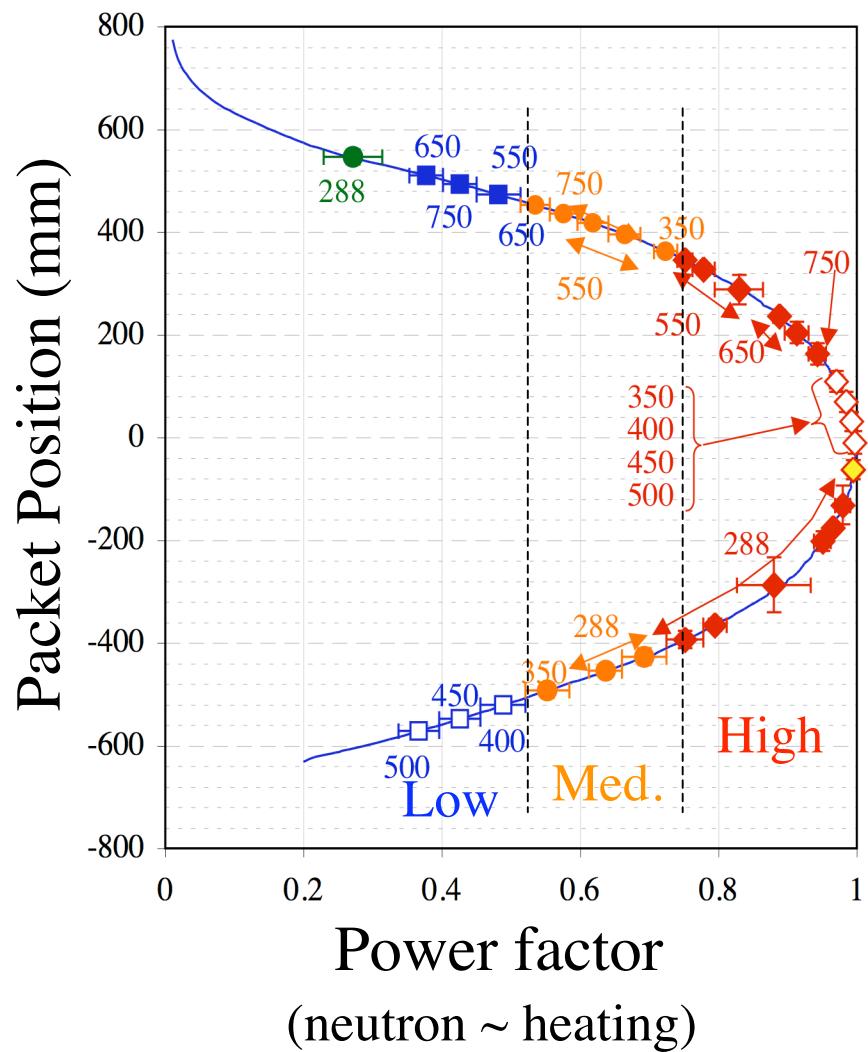
- 9 capsules for 4 cycles
- 2 capsules (switched) for 1 or 3 cycles
- Temperature: 275 - 750 °C
- Neutron dose: 1.6 - 6.2 dpa

Capsule ID	Materials	Target Temp.	Nominal Target Dose
UCSB-1	Mostly Fe-Based Metals	275 °C	1.7 dpa
UCSB-2		550 - 750 °C	2.4 to 4.2 dpa
UCSB-3		350 - 550 °C	4.5 – 5.1 dpa
UCSB-4		650 - 750 °C	5.5 – 5.8 dpa
UCSB-5		350 - 500 °C	6.0 – 6.2 dpa
UCSB-6A*		275 °C	1.7 dpa
UCSB-6B*		275 °C	4.6 dpa
UCSB-7		275 °C	6.0 – 6.2 dpa
UCSB-8		275 °C	5.6 – 5.7 dpa
UCSB-9		275 °C	4.2 – 5.2 dpa
UCSB-10		350 – 500 °C	2.4 – 3.8 dpa



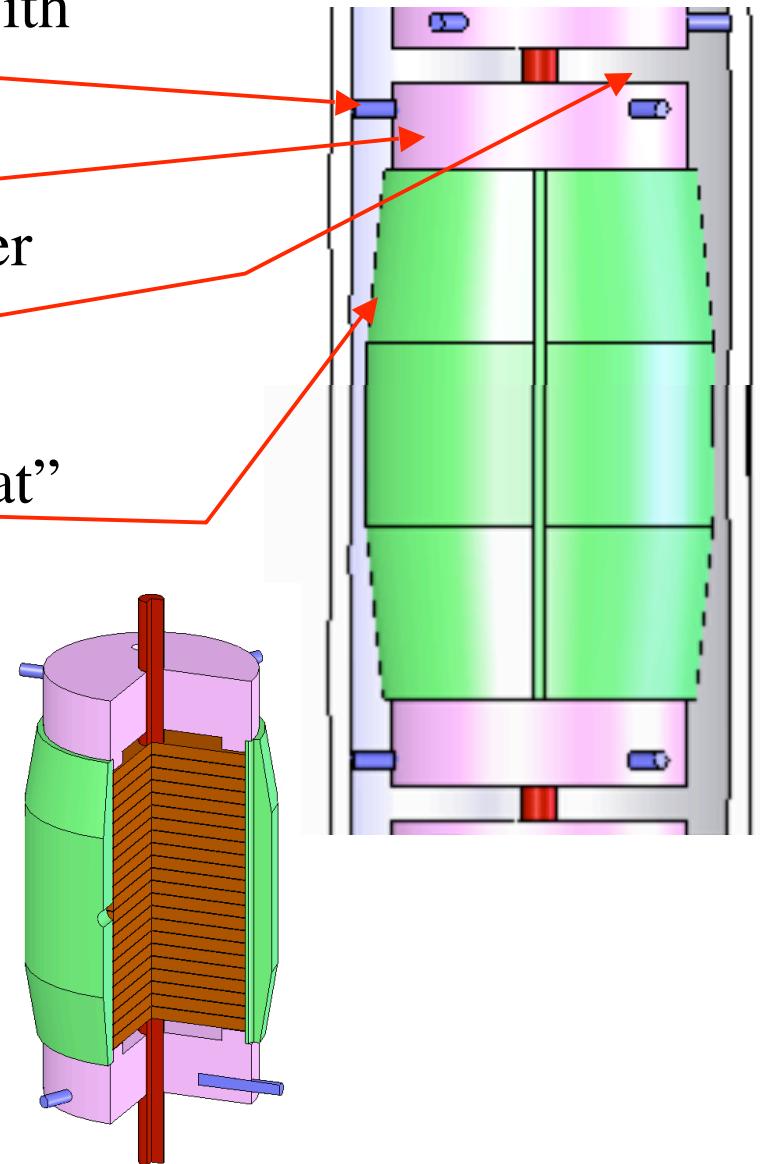
T - ϕt (- ϕ) Allocations

Distributed packets ($T_i = 288 \sim 750^\circ\text{C}$) in three flux (~ fluence) zones with two time variations to see flux effects

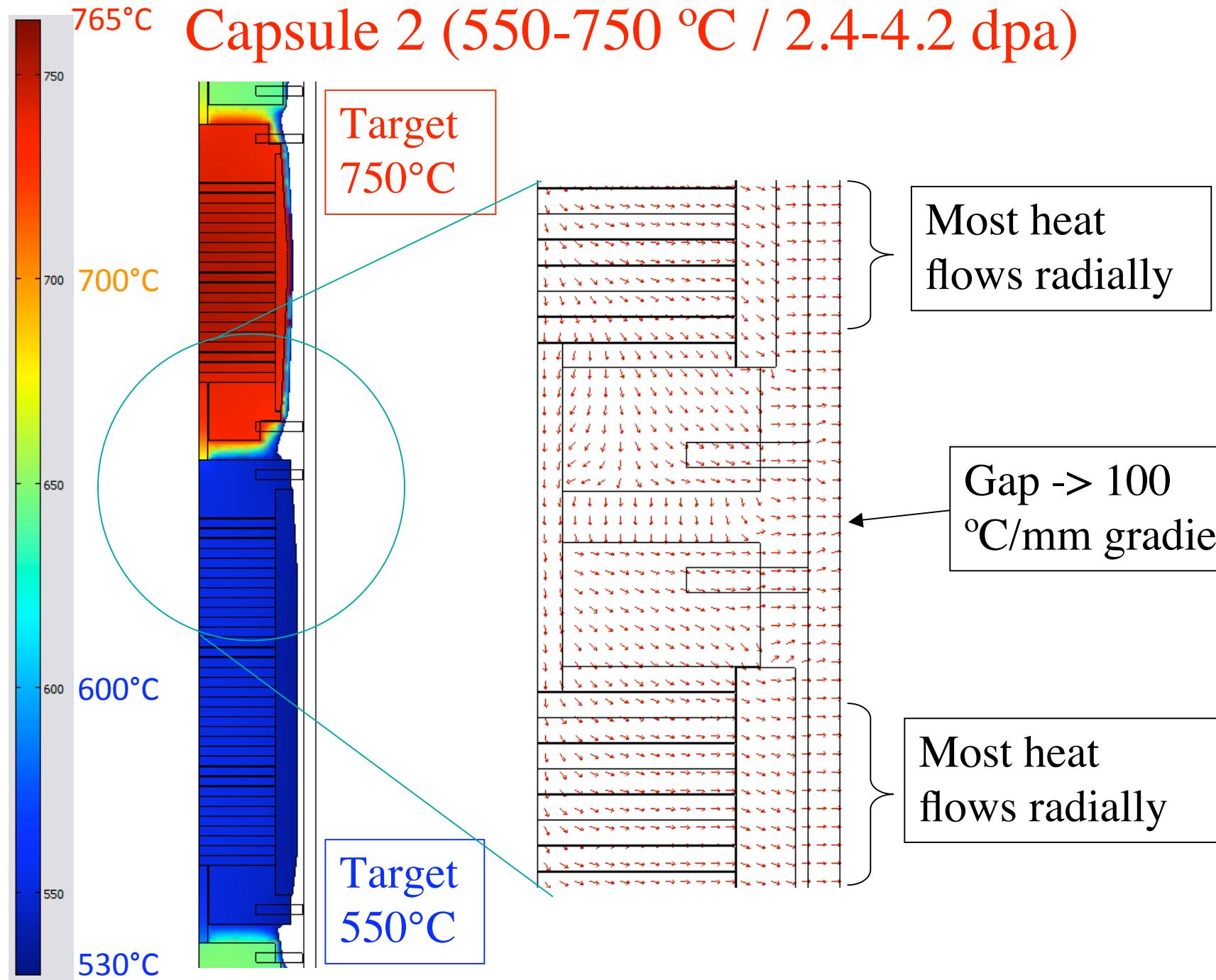


Basic Strategy for Thermal Design

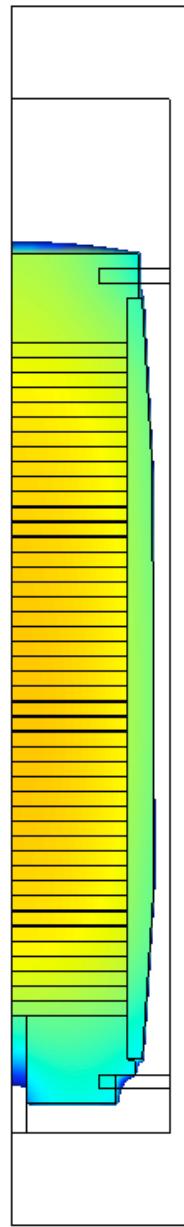
- Locator pins hold packet center with uniform gap
- High T ends (by sufficient heat generation & minimal heat transfer through the pins and large gaps) reduce axial heat flow
- Holder outer profile maintains “flat” temperature
- Press-fit load in the “pill-box” holder



DMC sample packet



Capsule 1 & 6 (Low & High Doses@288 °C)



- Small (< 10 °C) temperature variation within a packet
- “Same” temperature for two extreme cases

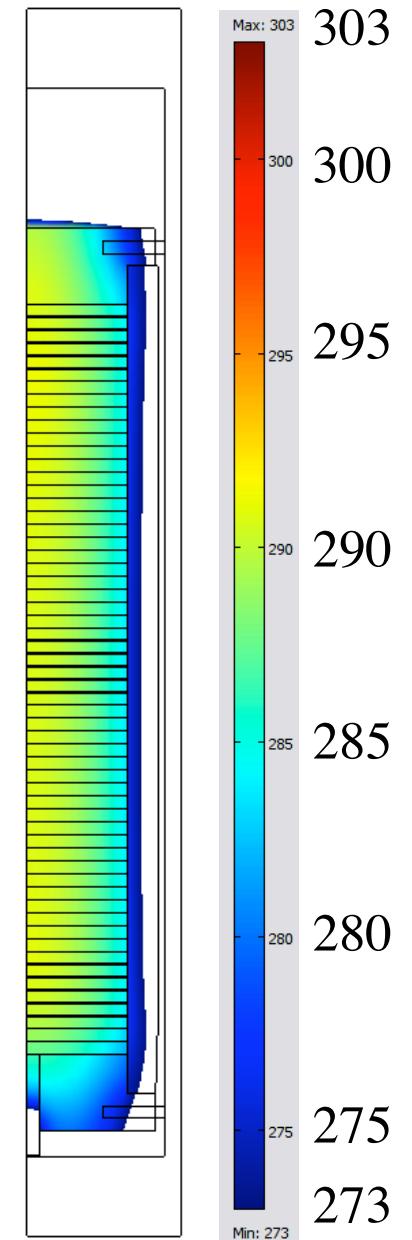
PF: 26.5%
80% Helium
20 % Argon

Specimen temperature:
286 – 294 °C

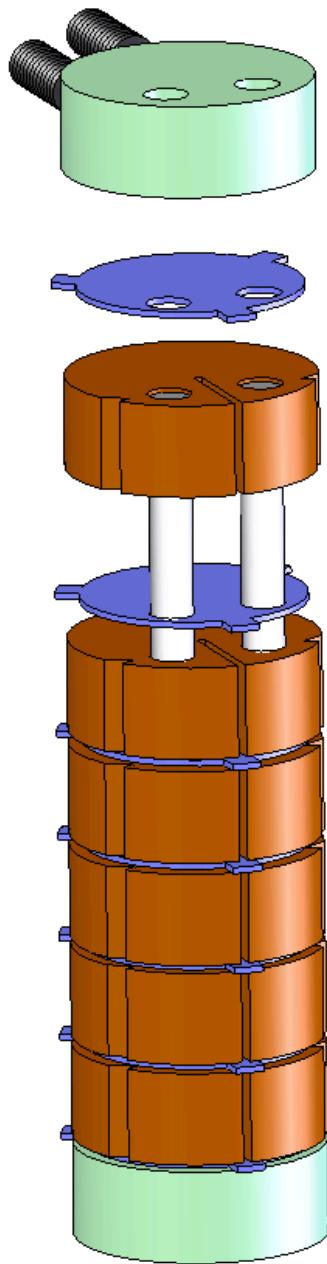
PF: 99.5%
100% Helium
0 % Argon

Specimen temperature:
276 – 294°C

SiC T-monitors included for verification



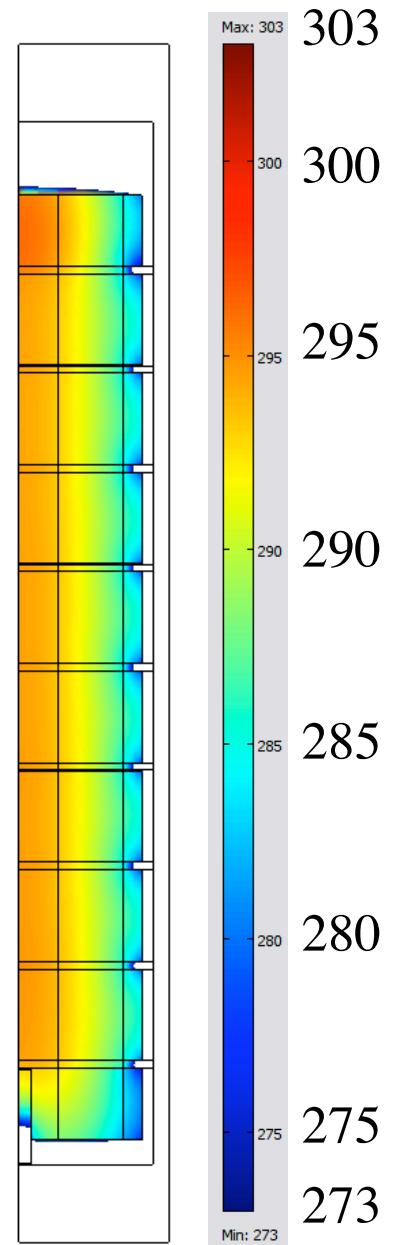
Fracture Specimens



Each geared insert (purple) has 5 – 20% of area in contact with the capsule wall to control temperature of the adjacent specimens.

The rods (white) maintain concentricity with the inserts. The end caps (green) hold the rods with setscrews

PF: 99.5%
100% Helium
0 % Argon



Summary of Thermal Design

- Axial T variation: $\pm 3.5 \sim 8$ °C
- Radial T variation : $\pm 3 \sim 8$ °C
(± 10 °C axially for the low T- high PF)
- Some extreme cases are shown below

Packet	Target (°C)	Range (°C)	Power Factor	Gas Gap (mm)	Gas (% Argon)
1-1	288	± 4.0	0.265	0.610	20
2-2	750	± 3.0	0.415	0.830	69
4-3	750	± 4.5	0.942	0.325	63
6A-1	288	± 9.0	0.995	0.240	0
10-7	550	± 3.0	0.245	1.031	55

Specimen Matrix

Total of 1375 specimens

Temp.(°C)	Irr. Code	dpa	DMC-thin	DMC-thick	He-Imp	DM	SSJ	DCT	CC	DFMB	CHW	Total	T-mon	Ni
288	H	5.6	36	119	-	-	36	25	24	42	4	286	2	-
	M	4.2	-	44	-	1	18	-	-	-	-	63	3	-
	M@high-f	4.6	-	-	-	-	-	8	-	-	-	8	-	-
	L	1.7	12	38	-	-	-	-	-	-	-	50	1	-
	L@high-f	1.7	10	53	-	-	-	-	-	-	-	63	1	-
350	H	6.1	21	54	-	-	-	-	-	-	-	75	2	-
	M	4.5	-	16	-	1	-	-	-	-	-	17	2	-
	M2	3.5	9	38	-	-	-	-	-	-	-	47	1	-
400	H	6.2	19	52	-	-	-	-	-	-	-	71	2	-
	L	3.1	6	39	-	-	-	-	-	-	-	45	1	-
450	H	6.2	19	47	-	-	-	-	-	-	-	66	2	-
	L	2.7	10	27	-	-	-	-	-	-	-	37	2	-
500	H	6.2	9	52	14	-	-	-	-	-	-	75	2	15
	L	2.3	10	25	-	-	-	-	-	-	-	35	1	-
550	H	4.9	29	69	12	-	18	-	-	14	-	142	3	13
	M	4.0	-	21	-	2	18	-	-	-	-	41	2	-
	L	3.0	10	26	-	-	-	-	-	-	-	36	2	-
650	H	5.6	4	49	12	-	18	-	-	-	-	83	3	13
	M	3.3	4	15	-	-	-	-	-	-	-	19	1	-
	L	2.4	4	15	-	-	-	-	-	-	-	19	1	-
750	H	5.9	13	39	10	-	-	-	-	-	-	62	2	11
	M	3.6	1	15	-	-	-	-	-	-	-	16	1	-
	L	2.7	2	17	-	-	-	-	-	-	-	19	1	-
Total			228	870	48	4	108	33	24	56	4	1375	38	52

Example Specimen Packets

SSJ2 Tensile Capsule



DCT stack up



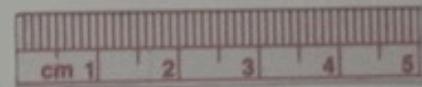
DFMB Capsule



DCM Capsule



Compression specimen & Chevron Wedge specimen Capsule

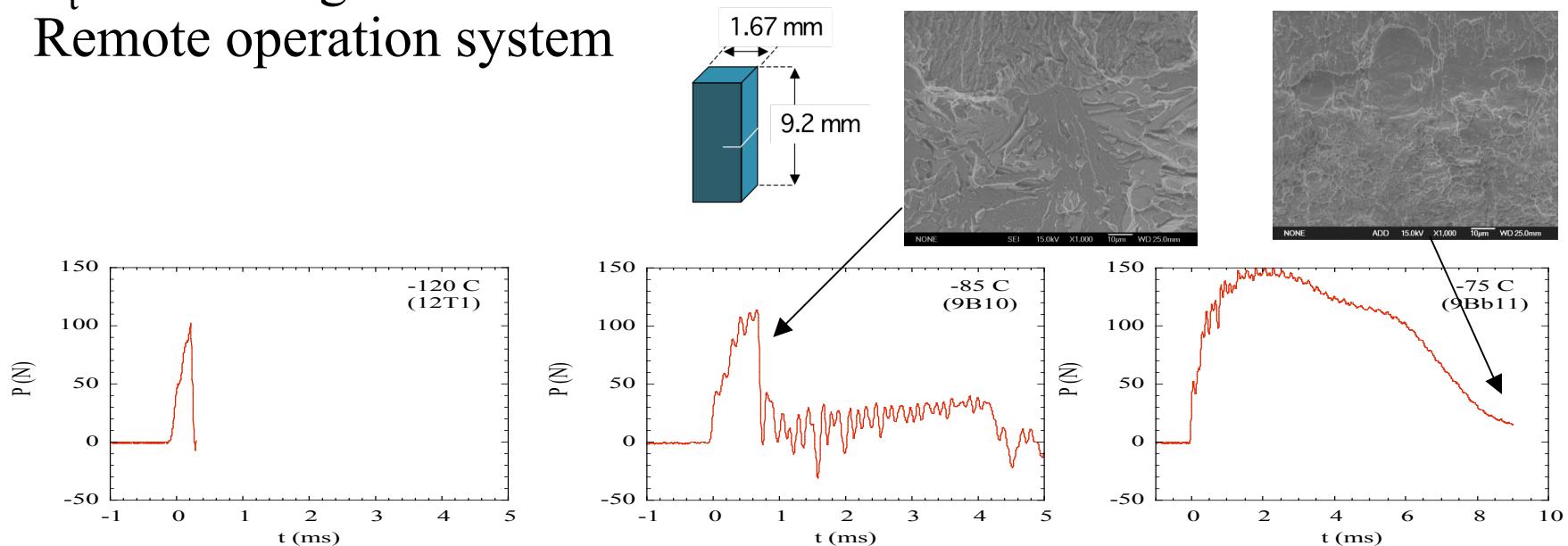
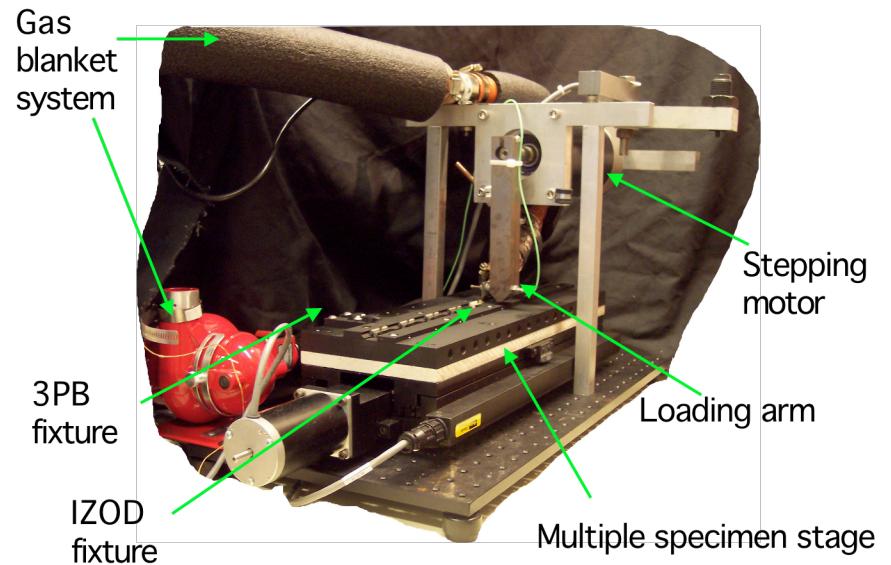


Plan for Post-Irradiation Examination

- PIE at INL, LANL, ORNL and PNNL collaborators hot cells involving UCSB grad students and post docs and as part of the lab base programs
- Mutual transfer techniques and expertise
- Optimize based on specific strengths and interests
- Open to other universities and collaborators
- Example - semi-automated fracture testing system

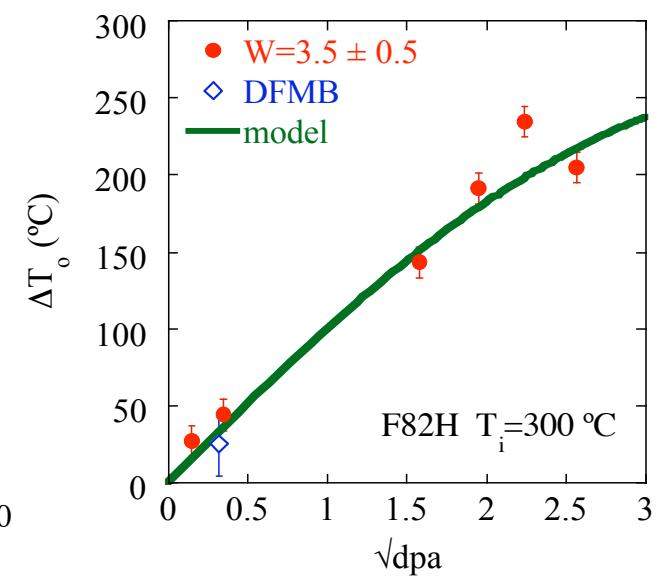
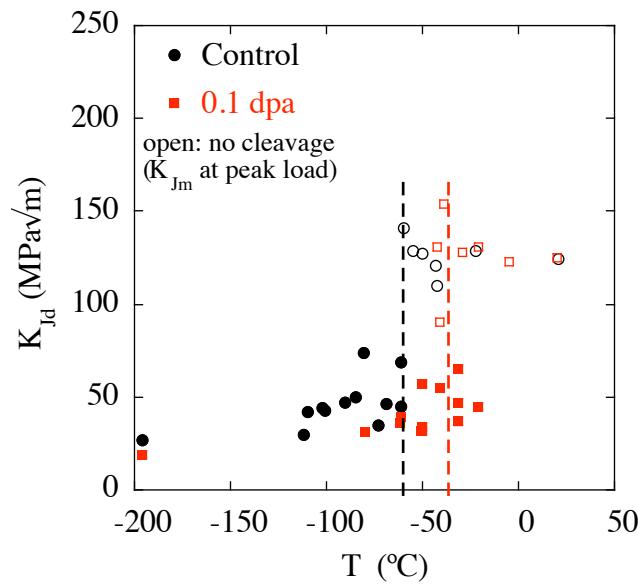
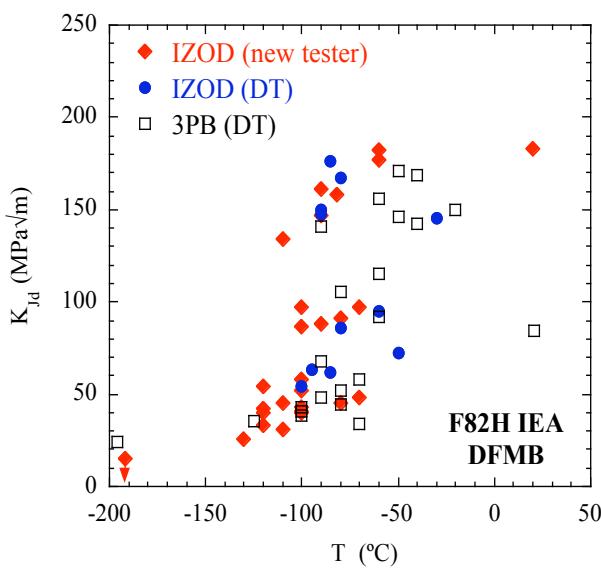
Tabletop Fracture Testing System

- Optimized for small specimens (DFMB, 1/3PCC)
- 9 locations for IZOD-type test; One 3(4)-point bend station
- Dynamic: 30 – 3000 mm/sec
- T control - Lig N₂ cooling or heat gun
- T_t monitoring w/ active TC
- Remote operation system



F82H DFMB K_{Jd}

- Consistent results over different machine and configuration
- Steep baseline transition around -80°C with some strain rate effect
- Clear $\Delta T_d \approx 25^{\circ}\text{C}$ for 0.1 dpa @ 290°C ; consistent with 1/3 PCC ΔT_o



Summary

- UCSB ATR (1) experiment provides a source of irradiated specimens as “lending library” to study mechanical properties, microstructure and thermodynamics in irradiated alloys.
- Total of 1375 specimens of TMS, NFA, model alloys and diffusion multiplies irradiated to 1.7 to 6.2 dpa at 8 nominal temperatures from 288 to 750 °C
- Gap profiling approach to achieve “uniform” axial temperature distribution within a packet of specimens
- Post-irradiation examination are being carried out with many collaborators by mutually transferring techniques and expertise
- Open to new collaborations